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Physics Division Activity Report

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Physics Division Activity Report

Abstract

This issue of the Physics Division Activity Report describes some of our activities and achievements in applied and basic science during the calendar year 2004. The report covers activities of the five Physics Division groups, which represent the main areas in which we serve Los Alamos National Laboratory and the nation: Biological and Quantum Physics, Hydrodynamics and X-ray Physics, Neutron Science and Technology, Plasma Physics, and Subatomic Physics. This report includes a message from the acting Physics Division Leader, Jack Shlachter; general information about the mission and organization of the Division; our staffing and funding data for the fiscal year; descriptions of the activities of each of our groups; highlights of major research efforts throughout the Division; and a list of our publications and conference presentations.

Contents

Division Leader's Introduction

The exciting research captured in this Physics (P) Division Activity Report for calendar year 2004 stands as a tribute to the outstanding professionalism of the technical staff within this organization. To say that 2004 was a tumultuous year for the Division and the Laboratory would be an understatement. The year began with change; on January 26, 2004, Susan Seestrom left her position as P-Division Leader to assume acting responsibilities as Associate Director (AD) for Weapons Physics. Later in the year Susan was selected and approved by the Regents of the University of California as the permanent AD. The domino effect brought me to the acting Division Leader position. I immediately asked Jeff Schinkel from P-23 to join the Division Office (P-DO) team in the acting Deputy Division Leader role; this recognized my appreciation of the need for a stronger emphasis on quality operations in P Division. Not long afterwards, I asked John Tapia to serve the Division Office as our acting Chief of Staff, replacing Pam French who joined Susan in the Directorate Office. With this many actors, there was some talk of forming a thespian society in P-DO.

Our annual Physics Division Review Committee (PDRC) meeting was conducted in February, and this year's focus was our contributions to the nuclear-weapons program, principally in radiography, experimental boost/thermonuclear physics, and experimental material studies. The nuclear-weapons program remains a core activity for P Division. We were pleased to receive PDRC confirmation of the high quality of our radiography research, and we are trying hard to keep this effort healthy despite the financial pressures associated with the DARHT II (Dual-Axis Radiographic Hydrodynamic Test facility) project. The exciting advances in proton radiography, resulting in spectacular images, and the outstanding science performed with this technique, are indeed a source of pride for us.

As expressed at our review, P Division has elevated the experimental boost/thermonuclear physics efforts to a high degree of visibility. In association with this emphasis, we reported on a novel, Laboratory-Directed Research and Development-funded effort on the short-pulse Trident laser. Great importance is placed on our engagement at the National Ignition Facility, and P Division has reported on our past year's progress in this area.

Perhaps the most dramatic event of the year was an unprecedented shut down of the Laboratory in the summer, which affected everyone in the Division. The shut down was called after two computer disks believed to contain classified information were reported missing and an intern sustained an eye injury from a laser. In an effort that spanned several months, many within P Division and several outside contributed to a review of our operations using a formal procedure referred to as a Management Self-Assessment (MSA). The MSA involved the review of documentation, detailed interviews with selected staff, and intense walkdowns of representative simulated activities. The results of the MSA have been incorporated into a set of local corrective-action plans, and we anticipate implementing these plans consistent with resources available.

At this time, the uncertainty that surrounds the Department of Energy (DOE) contract with the University of California (UC) continues to affect employees at both a personal and professional level. Despite these uncertainties and distractions, our staff continues to be honored with important awards and fellowships; for example, the Division received two American Physical Society fellowships in 2004.

This report, like P Division as a whole, is largely organized by physics disciplines, and we continue to lead experiments in areas of importance both for national security and basic science. Under the rubric of materials studies, one of the major strategic goals for the Laboratory, P-Division researchers continued their tradition of capturing complex, dynamic data in harsh environments on plutonium in subcritical tests. Two of our research highlights pertain to the Armando experiment conducted at the Nevada Test Site last year. An additional research highlight reports on experimental and theoretical studies of material strength using a technique developed by colleagues at the All-Russian Research Institute of Experimental Physics (VNIIEF).

Plasma physics remains a core capability of the Division with applications to nuclear-weapons performance, energy production, and astrophysics. This report addresses both inertial and magnetic fusion studies conducted within P Division at facilities both at Los Alamos and elsewhere. More fundamental plasma physics is covered in a paper on the flowing magnetized plasma experiment at Technical Area 35 while another highlight describes our efforts at enhancing combustion using a knowledge of plasma physics.

Our own in-house laser facility, the Trident laser, provides a diverse set of pulse-shape, energy, and wavelength options in a heavily diagnosed environment, available to both local and outside users, and Trident occupies an important place in P Division's portfolio. One of our research highlights describes exciting recent work on accelerating ions using ultra-high-intensity laser pulses.

Jack S. Shlachter, Physics Division Leader

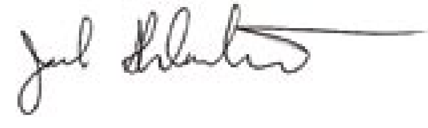
Radiography is one of the key technology drivers at the Laboratory and in P Division as well. Protons have been demonstrated to be the radiography tool of choice for applications involving multipulse "movies," and a paper study of the cost and feasibility of a single-axis proton radiography facility captures our planning for the future. The Armando subcritical experiment mentioned above was successful because of the development of a downhole x-ray radiographic capability known as Cygnus, and one highlight reports on this multiyear technology effort.

The strong neutrino effort at Los Alamos continues with plans about future experiments capable of detecting dark matter and low-energy solar neutrinos in the Cryogenic Low-Energy Astrophysics with Neon detector. Progress towards measurement of the neutron electric dipole moment, neutrino oscillations in accelerator experiments, and parity-violating gamma-ray asymmetry in the NPDGamma experiment are each described separately in highlight articles. Our work on PHENIX (Pioneering High-Energy Nuclear Interaction Experiment) continues at the Relativistic Heavy Ion Collider and is described in articles on muon, J/ψ, and charm quark production. Astrophysical data have resulted in an improved understanding of energy emission from gamma-ray bursts, the most extreme astrophysical energy sources known.

One of the applications of our information-processing studies in the biophysics arena is the development of models of the retina which can be applied to visual prostheses. For several years, we have been improving and applying the most sensitive magnetic sensors yet known, superconducting quantum interference devices, to the noninvasive study of the electrical activity in the brain. This work is now coupled with ultra-low-field nuclear magnetic resonance and could represent a major breakthrough for our biophysics team. How to handle subgrid phenomena in large-scale computer codes is a widespread problem, and one of our research highlights discusses stochastic closure techniques for multiscale simulations.

The atomic physics section of this activity report includes three papers covering a broad range of topics. One highlights the use of trapped ions as a testbed for quantum simulations of condensed-matter systems. Another article provides an overview of our work with photonic crystal fibers, one of the success stories of modern photonics. Finally, a fundamental-physics study with profound implications involves our efforts to measure a time variation to the fine structure "constant" known as alpha.

I believe these research highlights speak for themselves about the quality of research in P Division. Overall, 2004 was an enormously eventful year at Los Alamos National Laboratory, yet we remain optimistic that the Laboratory will continue to prove that UC management is sound and accountable so that our research can continue at the high level expected by our leadership, our scientists, and the nation.



Mission and Goals

The mission of Physics (P) Division is to further our understanding of the physical world, to generate new or improved technology in experimental physics, and to establish a physics foundation for current and future LANL programs.

The goals of P Division are to

- provide the fundamental physics understanding supporting LANL programs;
- investigate the basic properties of nuclear interactions, high-energy-density and hydrodynamic systems, and biological systems with a view toward identifying technologies applicable to new LANL directions;
- identify and pursue new areas of physics research, especially those to which the unique capabilities of LANL may be applied;
- explore interdisciplinary areas of scientific endeavor to which physical principles and the methods of experimental physics can make an important contribution; and
- maintain strength in those disciplines that support LANL's mission.

P Division pursues its goals by

- establishing and maintaining a scientific environment that promotes creativity, innovation, and technical excellence;
- undertaking research at the forefront of physics with emphasis on long-term goals, high risks, and multidisciplinary approaches;
- fostering dialogue within the Division and the scientific community to realize the synergistic benefits of our diverse research interests;
- encouraging the professional development of each member within the Division; and
- conducting all of its activities in a manner that maintains a safe and healthful workplace and protects the public and the natural environment.

Organization

J.S. Shlachter Division Leader
J.E. Schinkel* Deputy Division Leader
J.P. Tapia* Chief of Staff

Program Development

G.H. Canavan
Scientific Advisor and LANL Senior Fellow

D.M. Coates
Industrial Partnership Coordinator

Program Execution

W.C. Louis
Nuclear Physics Program Manager

A. Hauer
Thermonuclear Experiments PE† Manager

F.J. Wysocki*
Boost Physics PE Manager

R.E. Reinovsky
Pulsed Power Hydrodynamics Program Mgr.

G.A. Wurden*
Fusion Energy Project Manager

P-21: Biological and Quantum Physics

C.C. Wood, *Group Leader*
W.R. Scarlett, *Deputy GL*
S.M. Glick, *Deputy GL*

P-22: Hydrodynamic and X-ray Physics

D.W. Scudder, *Group Leader*
J.B. Aubrey, *Deputy GL*

P-23: Neutron Science and Technology

R.D. Fulton, *Group Leader*
B.K. Park, *Deputy GL*

P-24: Plasma Physics

C.W. Barnes, *Group Leader*
C. Munson, *Deputy GL*
J.M. Ray, *Deputy GL*

P-25: Subatomic Physics

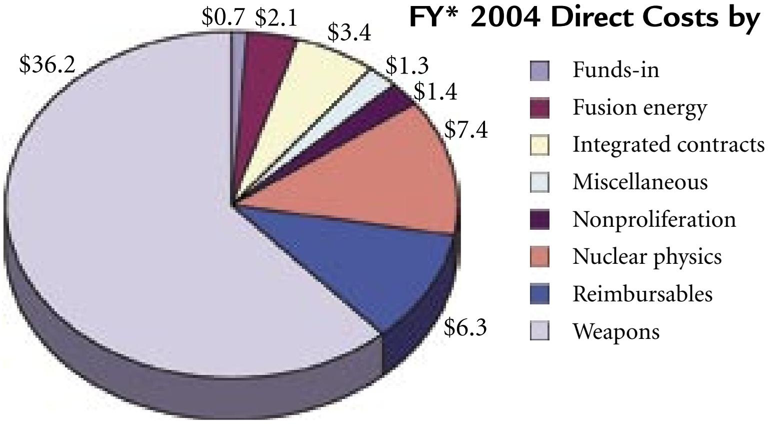
M.D. Cooper, *Group Leader*
J.S. Kapustinsky, *Deputy GL*
W.S. Wilburn, *Deputy GL*

*Acting

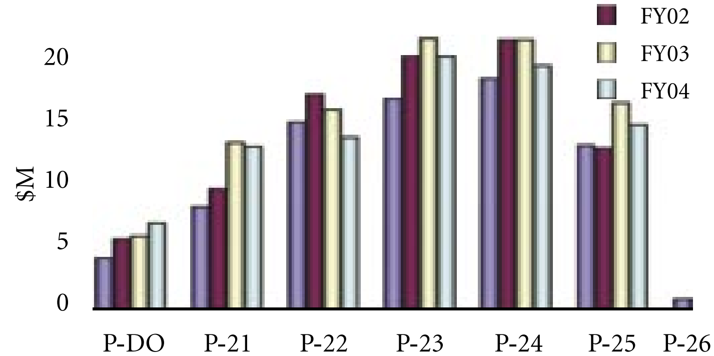
†PE = Program Element

Financial and Staffing Data

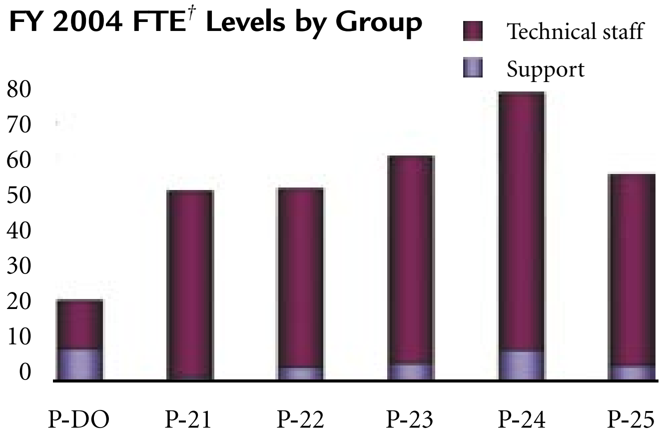
FY* 2004 Direct Costs by Funding Source ($M)



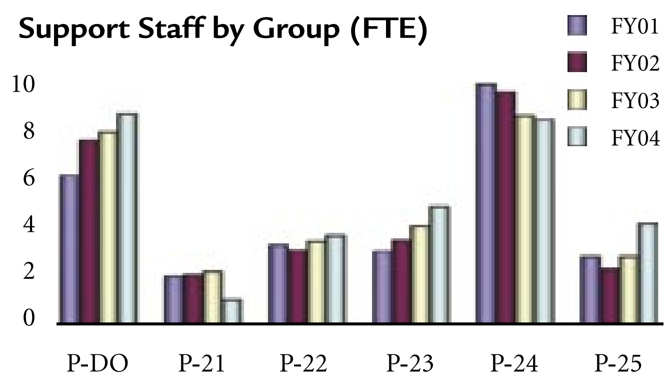
Total Operating Costs by Group



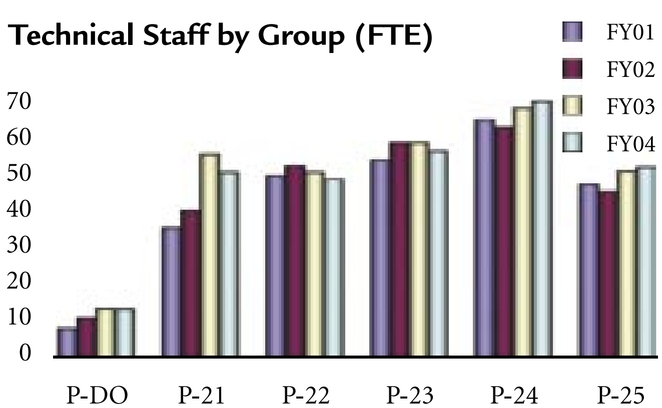
FY 2004 FTE† Levels by Group



Support Staff by Group (FTE)



Technical Staff by Group (FTE)



* Fiscal year

† Full-time equivalent

P-21: Biological and Quantum Physics Group

Charles Wood, Group Leader
Robert Scarlett and Stephen Glick, Deputy Group Leaders

The Biophysics Group (P-21) was founded in 1988 with the goal of applying the scientific and technical resources of Physics (P) Division to the biosciences. In October 2002, P-21 broadened its scope to become the Biological and Quantum Physics Group with the addition of the Quantum Information Team from P-23. This organizational change was initiated by P-Division leadership for two reasons. First, P-21 has longstanding experience in supporting entrepreneurial projects for non-DOE government agencies such as the National Institutes of Health, the Department of Defense, and the intelligence community, many of which are key sponsors for work in quantum-information research. Second, the Quantum Information Team and the Biophysics Group share common interests in the physics of information at all levels, from quantum information processing, computing, and cryptography to biological information processing by the nervous system. This common focus on the basic science and applications of information processing has already led to numerous constructive interactions between the biological and quantum components of P-21.

A new research interest in P-21 is the science and application of aerosols. Activities include measuring the background levels of biological organisms in public areas, detecting battlefield use of biological weapons, and monitoring and characterizing beryllium particles in the workplace.

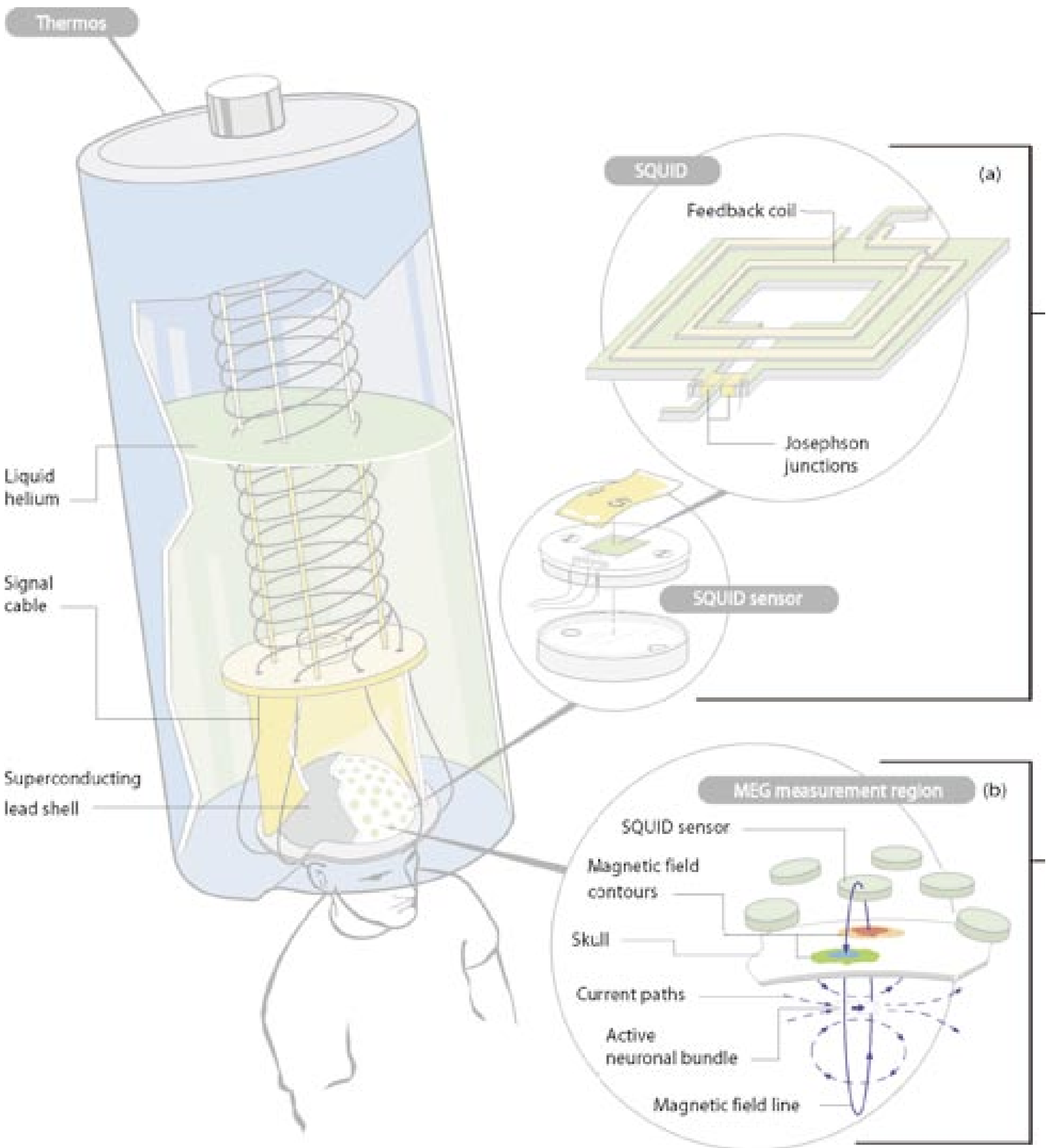
Biological Physics

P-21's historical mission has been to contribute to an understanding of biological phenomena by means of the scientific, technical, and conceptual resources of physics; to use biological systems to elucidate general physical principles underlying complex phenomena; and to apply, where appropriate, our scientific and technical capabilities to core LANL programs. Just as the 20th century is regarded as the century of the physical sciences, the 21st century will likely become the century of the biological sciences. P-21 and biophysics as a discipline are well positioned to contribute to this biological revolution in progress through our emphasis on understanding biological systems using the scientific, technical, and conceptual resources of physics. Recent advances in biophysical measurement and in molecular biology are beginning to allow detailed physical understanding of biological phenomena that were previously understood only in qualitative terms. P-21 is well placed by virtue of its capabilities and research interests to contribute significantly to this important trend in the biosciences. In addition to the goal of achieving a physical understanding of biological phenomena, the biophysical research in P-21 shares a number of other common characteristics. Specifically, we investigate the relationships between structure, dynamics, and function of biological phenomena over a wide range of scales (e.g., from biomolecules to the whole human brain). We also make extensive use of detection, imaging, and reconstruction techniques (e.g., x-ray crystallography, single-molecule electrophoresis, high-speed photon-counting optical imaging, magnetic resonance imaging [MRI], and magnetic-field measurements using technologies based on superconducting quantum interference devices [SQUIDs, Figure 1]). Finally, we attempt to achieve a detailed interplay between high-resolution physical measurements and large-scale computational modeling and analysis of complex systems.

We depend heavily on the tight connection and daily interactions between biologists and physical scientists within the group, the Division, and the Laboratory, and we apply the knowledge, techniques, and capabilities developed in our biological studies to national-security problems and those of specific interest to LANL when our ongoing efforts can offer unique solutions and significant mutual benefit. For example, P-21 has developed a new approach to the problem of "closure" in large-scale numerical models based on

P-21 Group Description

Figure 1. The magnetoencephalography (MEG) helmet's array of SQUID sensors and the superconducting lead shell are cooled by immersion in liquid helium. Each SQUID sensor contains a coil of superconducting wire that receives the brain fields and is magnetically coupled to the SQUID, which produces a voltage proportional to the magnetic field received by the coil. A computer program converts the SQUID data into maps of the currents flowing throughout the brain as a function of time. (a) The magnetic field lines that pass through the square hole at the SQUID's center determine the phases of electron waves circulating in the SQUID's superconducting region (green): the waves' interference is proportional to the magnetic flux over the hole. Because superconductors have no electrical resistance, the interference can be measured only by interrupting the superconductor with small regions that have electrical resistance—the two Josephson junctions—so that voltage drops will develop across them. The voltage measured across the junctions is proportional to the magnetic flux over the SQUID's square hole. The feedback coil magnetically couples the SQUID to the pick-up coil in the SQUID sensor. A SQUID is typically 10 to 100 μm on a side. (b) The colored contours show how the magnetic field produced by neural brain currents (dashed arrows) changes in intensity and polarity over the skull's surface. In the red region, the field is most intense in a direction pointing out of the skull. In the blue region, the field is most intense in a direction pointing into the skull.



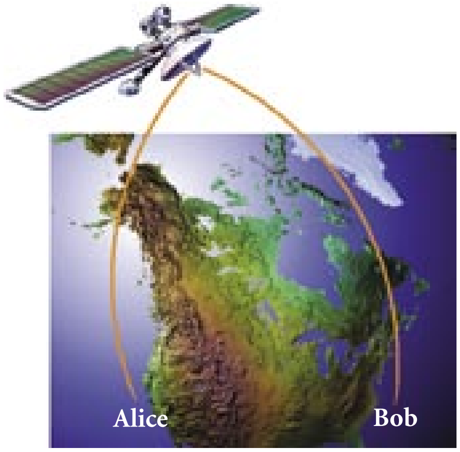


Figure 2. Illustration of the QKD communication between "Alice" and "Bob."

partial differential equations. This work is the focus of a Laboratory-Directed Research and Development-Director's Reserve funded project involving members of the ocean-, flow-, and weapons-modeling communities.

Quantum Information Science

A key discovery of 20th century science was the realization that information is physical. The representation of "bits" of information by classical physical quantities, such as the voltage levels in a microprocessor, is familiar to everyone and is the basis of the "information explosion" of the latter half of the 20th century. More recently, the field of quantum information science has made great progress in understanding information in terms of the laws of quantum mechanics. For example, a unit of quantum information, known as a "qubit," can be represented by single-photon polarization states. Remarkable new capabilities in the world of information security have been predicted that make use of quantum-mechanical superpositions of information, a concept that has no counterpart in conventional information science. For example, quantum cryptography allows two parties to communicate securely even in the presence of hostile monitoring by a third party (as described below). P-21's Quantum Information Team has experimental projects under way in quantum cryptography, quantum computation, quantum optics with trapped strontium ions, and atom interferometry with Bose-Einstein condensates.

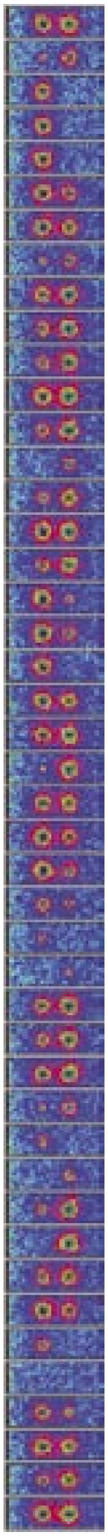
Quantum cryptography. One of the main goals of cryptography is for two parties ("Alice" and "Bob," Figure 2) to render their binary communications unintelligible to a third party ("Eve"). This can be accomplished if Alice and Bob both possess a secret random-bit sequence, known as a cryptographic key. For example, in "one-time-pad" encryption, Alice adds the key to the original message, known as plaintext, and communicates the sum (ciphertext) to Bob. He is able to recover the plaintext by subtracting his key from the ciphertext, but Eve, who is assumed to have monitored the transmitted ciphertext, is unable to discern the underlying plaintext through the randomization introduced with Alice's key. So, although key material conveys no useful information in itself, it is a very valuable commodity, and methods for Alice and Bob to generate key material securely are correspondingly important. Using quantum key distribution (QKD), Alice and Bob can create shared cryptographic key material whose security is ensured by the laws of quantum mechanics.

QKD offers many security and ease-of-use advantages over existing key-distribution methods. Traditional key distribution using trusted couriers requires cumbersome security procedures for preparing, transporting, and handling the key before any communications can take place and may even be impractical (e.g., rekeying a satellite). In contrast, quantum keys do not exist before the QKD transmissions are made, and a key can be generated at message-transmission time. Public-key cryptography also avoids many of the difficulties of key distribution by courier but provides only the conditional security of intractable mathematical problems, such as integer factorization. Accurate assessment of an adversary's computing power over the useful lifetime of encrypted information, which may be measured in years or even decades, is notoriously difficult—unanticipated advances in fields such as quantum computation could render public-key methods not just insecure in the future but also retroactively vulnerable. QKD could be used for real-time key generation in cryptographic applications where this long-term risk is unacceptable. Recent progress in QKD was described in a research highlight in last year's Physics Division Activity Report.

P-21's QKD Team leads the world in many aspects of quantum cryptography. We have demonstrated all aspects of quantum key exchange over 48 km of fiber at LANL and are leading a demonstration of these capabilities over an existing fiber network for the U.S. government. Free-space quantum cryptography was invented by our team, and we have now fully demonstrated the practicality of this approach for a variety of applications over a 10-km range. The QKD Team and six other institutions in the Information Society Technologies (IST) QuComm collaboration were named co-winners of the European Union's 1M-Euro Descartes Prize for Research. The IST-QuComm collaboration is made up of research groups in Sweden, Germany, France, Switzerland, Austria, and the United Kingdom, in addition to the Los Alamos team.

Quantum computation. With two or more qubits, it becomes possible to consider quantum logical-"gate" operations in which a controlled interaction between qubits produces a (coherent) change in the state of one qubit that is contingent upon the state of another. These gate operations are the building blocks of a quantum computer, which in principle is a much more powerful device than any classical computer because the superposition principle allows an extraordinarily large number of computations to be performed simultaneously. In 1994, it was shown that this "quantum parallelism" could be used to efficiently find the prime factors of composite integers. Integer

Figure 3. A time series of two ions simultaneously undergoing quantum jumps.



factorization and related problems that are computationally intractable with conventional computers are the basis for the security of modern public-key cryptosystems. However, a quantum computer running at desktop-PC speeds could break the keys of these cryptosystems in only seconds (as opposed to the months or years required with conventional computers). This single result has turned quantum computation from a strictly academic exercise into a subject whose practical feasibility must be urgently determined. The architecture of a quantum computer is conceptually very similar to a conventional computer—multiqubit, or "multibit," registers are used to input data. The contents of the registers undergo logical-gate operations to effect the desired computation under the control of an algorithm, and a result must be read out as the contents of a register.

Many fundamental issues key to quantum-science applications remain insufficiently investigated. Members of the P-21 Quantum Information Team are actively engaged in several of these areas. For example, we are using trapped ions to measure the randomness of atomic transitions (Figure 3), which constitute a key test of the predictions of quantum mechanics. Other studies involve ultracold atoms collapsed into a Bose-Einstein condensate. These experiments, more fully described in last year's report, contribute to the worldwide goal of a complete understanding of this forefront of physical science.

Another important direction is quantum simulation, using one quantum system to simulate another. For example, the particle level modeling of a many-body quantum system is intractable for a realistic case, but may be simulated by a configuration of trapped ions. Measurements of such systems could increase understanding of condensed matter systems such as high-T_C superconductors. In a related effort, members of P-21 have initiated an "ion trap foundry" initiative to combine industrial-scale microfabrication techniques with trapped-ion quantum simulation and quantum computing. This work is an outgrowth of collaborations at Los Alamos involving P, Theoretical, and Chemistry Divisions and involves a developing collaboration between quantum scientists at Los Alamos and microfabrication experts at Sandia National Laboratories. Such an "ion trap foundry" would significantly accelerate progress toward trapped-ion quantum computation, an important national-security goal.

P-22: Hydrodynamics and X-ray Physics Group

David Scudder, Group Leader
Joysree Aubrey, Deputy Group Leader

The activities of the Hydrodynamics and X-ray Physics Group (P-22) help support LANL's mission of ensuring the safety and reliability of the nation's nuclear stockpile. Group members are also involved in research that addresses fundamental issues related to hydrodynamic phenomena at extreme pressures, high-energy-density plasmas, fusion physics, and exploration of the dynamic properties of materials. Other endeavors have led to innovations with commercial potential.

The tremendous challenge of certifying the stockpile in the absence of testing requires that we marshal all the capabilities and resources at our disposal. As the materials in nuclear weapons age, they become further and further removed from the states under which they were tested. Defects in devices and engineering modifications have introduced uncertainties in performance and reliability. To address these issues, we must have a fundamental understanding of the physical processes involved in the performances of nuclear weapons and the limits of models developed and benchmarked during the testing era. P-22 contributes to this challenge in a number of ways through the re-analysis and re-evaluation of archival Nevada Test Site (NTS) data in support of stockpile stewardship activities and validation of weapons design codes, diagnostic development and training to enhance the test-readiness posture of the nation, and the execution of above-ground experiments with the aim of understanding and resolving weapons-physics issues. The group has the resources to assemble multidisciplinary teams to address these challenges. Our involvement with various experimental programs has required efforts in diverse areas such as optics, hydrodynamics, plasma physics, radiation transport, pulsed-power science, weapons physics, x-ray spectroscopy and imaging, microwaves, electromagnetics, and nuclear and atomic physics.

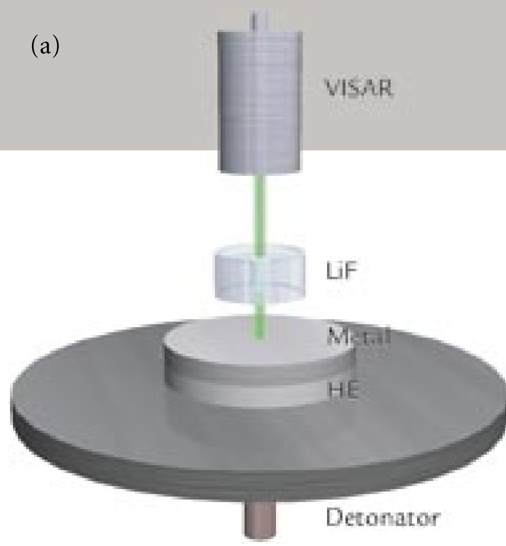
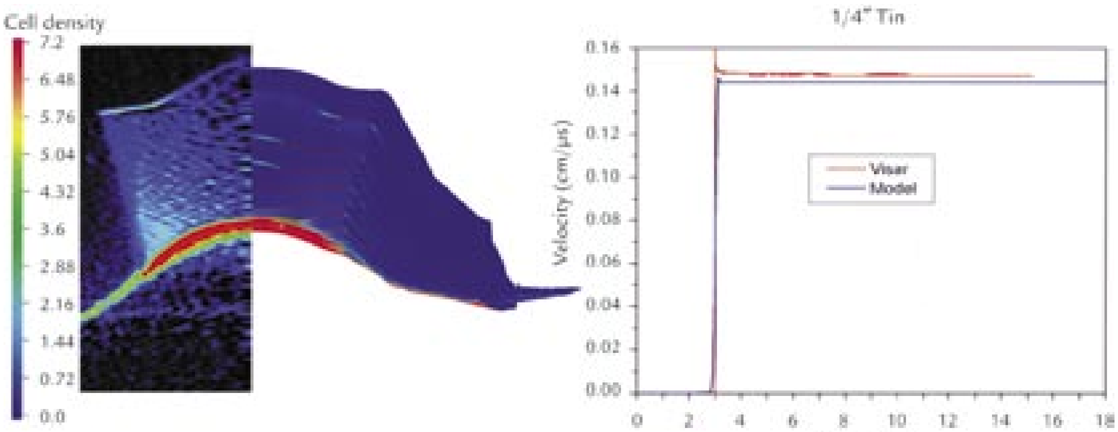


Figure 1. (a) Schematic of the experimental configuration used to study the behavior of shocked metals. VISAR and Asay windows were employed to measure surface velocities. (b) The same set-up was used (without the Asay window) for experiments diagnosed with proton radiography (pRad) and VISAR.

Dynamic Properties of Materials

Researchers in P-22 have used a variety of diagnostic tools to investigate damage and melting in materials which are subjected to explosively driven shocks. The suite of diagnostics include VISAR (velocity interferometry for surfaces of any reflectivity), Asay windows, optical pyrometry, photon Doppler velocimetry, and radiography using x-rays and protons.

In a series of experiments designed to study mixed-mode damage in materials, disks of various metals, two inches in diameter and of different thicknesses were attached to cylinders of high explosives (HE: PBX-9501, two inches in diameter and one-half inch thick). A lithium fluoride (LiF) window was placed a few millimeters above the samples. This is known as an Asay window. The



(a) (b)

Figure 2. The time-dependent evolution of shock-melted tin was observed using pRad and VISAR. (a) A comparison of the areal densities in a pRad image with a calculation done by Michael Prime (ESA-WR) is shown. (b) The VISAR trace of the time-dependent surface velocity is compared to the results from the simulation.

experimental set-up is shown in Figure 1(a). The explosives were point-detonated and the time-dependent behavior of the metal coupons was tracked using VISAR. The VISAR was used to detect both the free-surface velocities and the times of arrival of the spalled layers at the Asay window. The ability to record the details of velocity structure during an experiment is very important for understanding the physics of dynamic processes. Similar experiments were diagnosed using multiframe proton radiography (pRad) but without the Asay window [Figure 1(b)]. The combination of multiple radiographic images and spatially distributed VISAR data from the same experiment provided theorists with high-quality data for benchmarking materials models. Detailed continuous velocity measurements between images contributed to the overall understanding of dynamic processes.

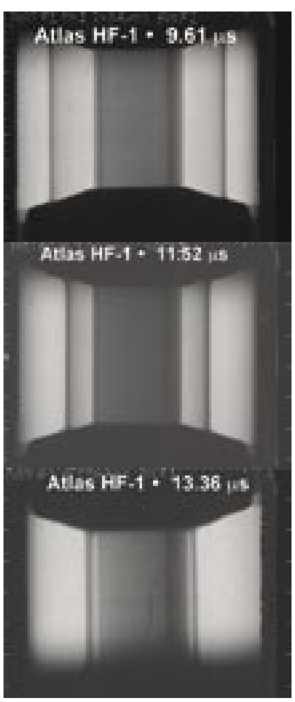


Figure 3. Liner implosion experiments on Atlas verified fundamental dynamics and demonstrated reproducibility.

Well-characterized samples of copper, aluminum, tin, and tantalum were used. Figure 2 shows a comparison of a pRad image of shock-melted tin with a simulation generated by one of our collaborators in Engineering Sciences and Applications (ESA) Division. The comparison of the calculation with VISAR data is also shown.

In support of the Dynamic Materials Campaign, we have conducted research in collaboration with the Materials Dynamics Group (DX-2) and the Neutron Science and Technology Group (P-23) on the production of ejecta from the surfaces of shocked materials and subsequent transport of the particles into gas. These experiments were performed on tin targets at the LANL gas-gun facilities. Detailed information about the densities and velocities of particle clouds generated from shocked surfaces is necessary for the development of models of the phenomenon. Another series of experiments is being conducted (in partnership with DX-2) to investigate the behavior of shocked materials off the principal Hugoniot curve. The resulting data provide information about the target material's equation of state (EOS) under pressure and temperature conditions that are not easily accessible by other means. In collaboration with P-23, DX-2, and the Polymers and Coatings Group (MST-7), P-22 staff used optical pyrometry to measure the temperature of shocked materials to elicit information about solid-solid and solid-liquid phase transitions. Such information has been very valuable in testing EOS models of materials

Pulsed-Power Hydrodynamics

Members of the group have done pioneering work in developing and applying pulsed-power facilities to explore

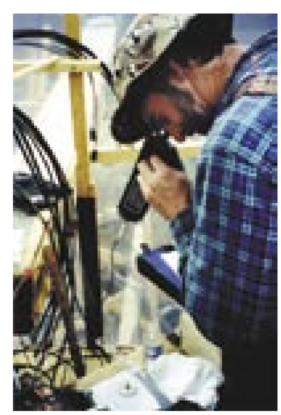


Figure 4. Leonard Tabaka (P-22) examines a Faraday fiber before conducting an experimental shot carried out in Sarov, Russia. Scientists from LANL and VNIIEF performed a series of experiments aimed at determining the dynamic yield strength of copper. These "Russian High Strain-Rate" experiments are important to refine and validate computational models of dynamic material strength under high-strain and strain-rate conditions.

hydrodynamic phenomena at extreme pressures and convergent geometries. Under the Pulsed-Power Hydrodynamics (PPH) program, experiments were conducted to address issues related to LANL's main mission of supporting the nuclear stockpile in the absence of testing. The 4.6 MJ Pegasus II and the 23 MJ Atlas facilities were used to study dynamic material properties under extreme conditions. Energy stored in capacitor banks was delivered to a central cylindrical liner. The axial currents flowing through the liner gave rise to J × B forces, which drove the liner radially inwards at speeds of kilometers per second towards the central axis. High-precision radiography yielded information about the time-dependent behavior of the liner (Figure 3) and demonstrated reproducibility of the implosion. Experiments included studies of convergent material flow in asymmetric geometries. The data were used to validate models in modern weapons design codes. Other experiments looked at the growth of preformed perturbations during implosions, strength at high strain-rates, frictional forces between materials with differential velocities, and spall in materials driven by 50 kbar convergent shocks. The future of the LANL PPH program is full of challenges and exciting new opportunities. The Atlas facility has been moved to the NTS and was recommissioned during the summer of 2004. In addition to conducting experiments on the pulsed-power facilities at LANL, P-22 group members have had a long collaboration with scientists at the All-Russian Scientific Research Institute of Experimental Physics at Arzamas-16 (VNIIEF) (Figure 4). The Russians have developed large-scale explosive pulsed-power facilities capable of generating fields of thousands of Tesla. Joint experiments have explored instability growth in convergent geometries, magnetized target fusion, the design and development of a megajoule x-ray source, and the properties of materials in high fields and at cryogenic temperatures.

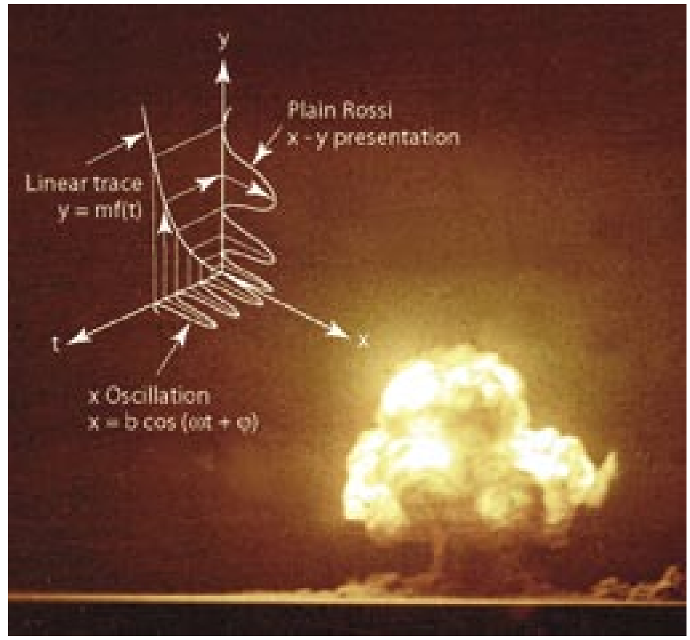


Figure 5. Archival photo of the Trinity event (July 16, 1945). The inset is a schematic representation of the Rossi technique.

Strongly Coupled Plasmas and Radiation Hydrodynamics

The understanding of the properties of strongly coupled plasmas and the interaction of these plasmas with radiation is important for fusion and weapons-physics applications. We are involved in various research projects in these areas using both local facilities and those elsewhere, such as the Z machine at Sandia National Laboratories (SNL) and the Omega laser at the University of Rochester. We are conducting investigating fundamental processes that are relevant to fusion and strongly coupled, multimaterial plasmas. The work is being done locally under a Laboratory-Directed Research and Development project and involves two experiments aimed at measuring the ion-ion diffusion coefficient and the temperature equilibration rate between ions and electrons in a dense plasma. We have also studied the propagation of radiation in materials using the x-ray source generated by SNL's Z machine, which generates currents of 20 MA and a peak electrical power of about 40 TW. This source has been used to study the physics of radiation-matter interactions.

NTS Data and Weapons Physics

The first alpha (neutron multiplication rate) measurement was performed by Bruno Rossi on the Trinity event (Figure 5). This diagnostic became a standard tool for assessing the nuclear and thermonuclear performances of devices fielded at the NTS and elsewhere.

Neutrons in a supercritical assembly increase exponentially according to the formula $N(t) = N_0 e^{\alpha t}$. If α is not a constant, then the equation is modified to $N(t) = N_0 e^{S\, \alpha(t)\, dt}$. The time-dependent neutron population is proportional to the resulting leakage of gamma radiation from the surface of the device. The exponentially increasing gamma flux is converted to an electrical current by a series of detectors that span the dynamic range of the signal. The electrical signal in turn is recorded on oscilloscopes driven by oscillators at appropriate frequencies. The Rossi technique consists of the superposition of the exponentially increasing signal on a sinusoidal trace (inset in Figure 5). The time-dependent behavior of the gamma radiation can be extracted by using the known frequency of the sine wave.

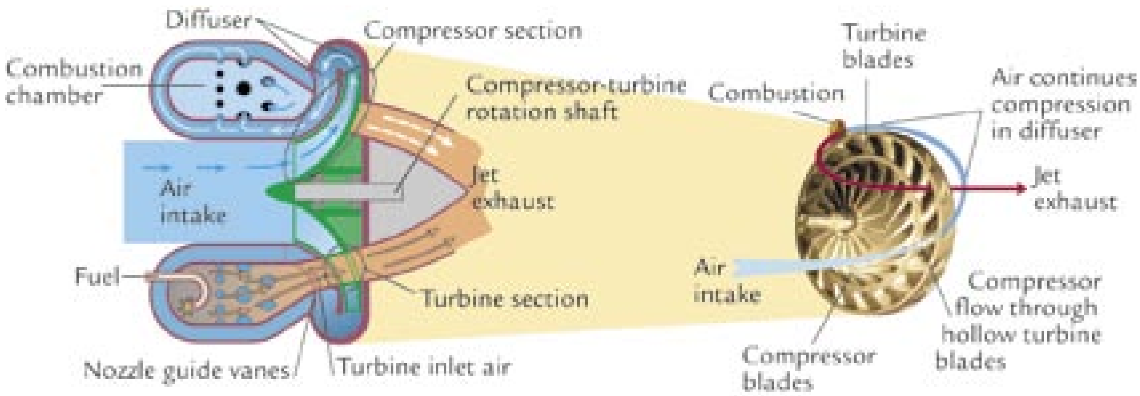


Figure 6. Composite drawing of the ASRT schematic and photo, showing how the ASRT operates. Air from the compressor section of the ASRT is channeled through the outer hollow turbine blades on the same rotor. The air, on its way to the combustion chamber, cools the turbine section allowing the engine to operate at higher temperatures. The fuel efficiency is increased in this case.

P-22 is the custodian of archival data from the NTS and is in the process of developing modern methods of analysis and applying them to nuclear events. We have completed work on software that automates the extraction of time and amplitude information from the film, eliminating the tedium (and possible errors) of manually obtaining the data points. New programs to generate gamma-flux and alpha (logarithmic derivative of the flux) curves from the data are under development. These codes will augment the existing software. In collaboration with our colleagues from Statistical Sciences (D-1), Weapons Response (ESA-WR), and Complex Systems (T-13), we are developing rigorous methods of error analysis for the data in order to deliver higher-fidelity information to the nuclear-weapons design and code development community. The re-analysis effort has given us new insights into the physics of individual devices and weapons systems. Diagnostic physicists who were responsible for designing and fielding the experiments on nuclear tests are also involved in the analysis, documentation, and mentoring activities within the group.

New Initiatives

A new type of engine developed by a group member, the Advanced, Single-Rotor Turbine (ASRT, Figure 6), was recently nominated for an R&D100 Award. The compressor and turbine are combined into a single piece, increasing reliability while reducing engine complexity and size, as well as fabrication and maintenance cost. Envisioned applications for this technology include portable power units and residential distributed power supplies, as well as small jet engines and turbo-shaft engines for turboprop aircraft, helicopters, and tanks. Centrifugal turbines could also be implemented in turbochargers for piston engines and turbopumps for liquid-fueled rockets, refrigeration, and applications in the chemical-processing industry.

A portable gamma-ray and neutron detector developed by another staff member in P-22 was also nominated for an R&D100 award. The detector, called GN-5, can be used to detect nuclear materials and explosives quickly and efficiently. The tool can be deployed at critical locations such as border crossings, airports, sports arenas, and power plants. The heart of the instrument is a high-purity germanium (HPGe) gamma-ray detector and a bismuth germanate (BGO) scintillator. There is also a pair of helium-3-filled neutron detectors, one of which is shielded with cadmium. Because the HPGe crystal operates at very low temperatures (80 to 110 K), it is placed in a vacuum cryostat that is attached to a miniature mechanical refrigerator. A small, commercial Stirling-cycle cooler (1 kilogram, 3.5 watts) can be used. The weight of the unit is 8 kilograms and the battery lifetime is around 12 hours. The GN-5 has a large library of gamma-ray spectral information for over 200 isotopes which enables it to identify complex spectra.

P-23: Neutron Science and Technology Group

Doug Fulton, Group Leader
Brent Park, Deputy Group Leader

The Neutron Science and Technology Group (P-23) executes a wide range of projects—spanning weapons physics and nuclear physics through fundamental and applied research. The core capabilities of the group are in the application of state-of-the-art techniques in particle and light detection and in the imaging and recording of transient events. Our efforts in weapons physics contribute to the national-security mission of LANL through the stockpile stewardship program by participating in the design and fielding of subcritical experiments (SCEs), small-scale dynamic experiments, and the reanalysis and archiving of data from past nuclear weapons tests. Our fundamental research contributes to science in support of LANL programs through studies on nuclear and weak-interaction physics and on state-of-the-art measurements of astrophysical phenomena such as solar neutrinos and ultra-high-energy gamma rays. Applied research includes the application of imaging and neutron technologies to problems relevant to national defense, homeland security, and industry. A number of the projects and programs described below are also featured in this report.

Weapons Physics

Members of P-23, working in collaboration with P-22 and various groups in Dynamic Experimentation (DX), Engineering Sciences and Applications (ESA), Applied Physics (X), Nuclear Materials Technology (NMT), and Materials Science and Technology (MST) Divisions, designed and executed the Stallion series (Vito, Mario, Rocco, and Armando) of SCEs.

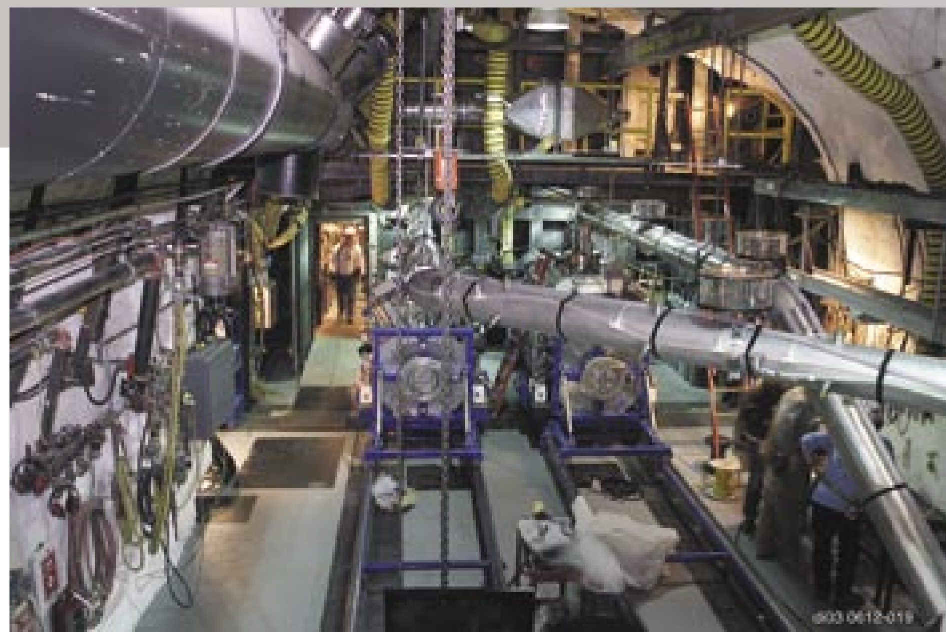


Figure 1. Armando subcritical experiment at the Nevada Test Site.

The purpose of Vito was to examine ejecta formation in a particular region of a weapon, and it successfully demonstrated the LANL "racklet" approach that facilitates rapid and cost-effective turnaround between SCEs. The racklet method was subsequently employed for Mario and Rocco. The goal of Mario and Rocco was to compare the properties of cast versus wrought plutonium. Armando, the last of the SCEs in the Stallion series, was successfully fielded in May of 2004 to verify the behavior of the target surface observed in Rocco and Mario shots.

The specific properties investigated in SCEs include ejecta formation, spall features, and surface temperature. Holography, used to measure ejecta-particle-size distributions, provide information about ejecta-particle transport in a gas environment. Another technique, soft x-ray imaging, was developed to measure ejecta-density distributions from shock-loaded metals. In a complementary experiment, proton radiography (pRad) was used for the first time to study material failure in depleted uranium and other samples. Surface temperature is measured with a high-speed, time-resolved, multiwavelength near-infrared surface pyrometer. All these methods provide data that contribute to our understanding of the strength,

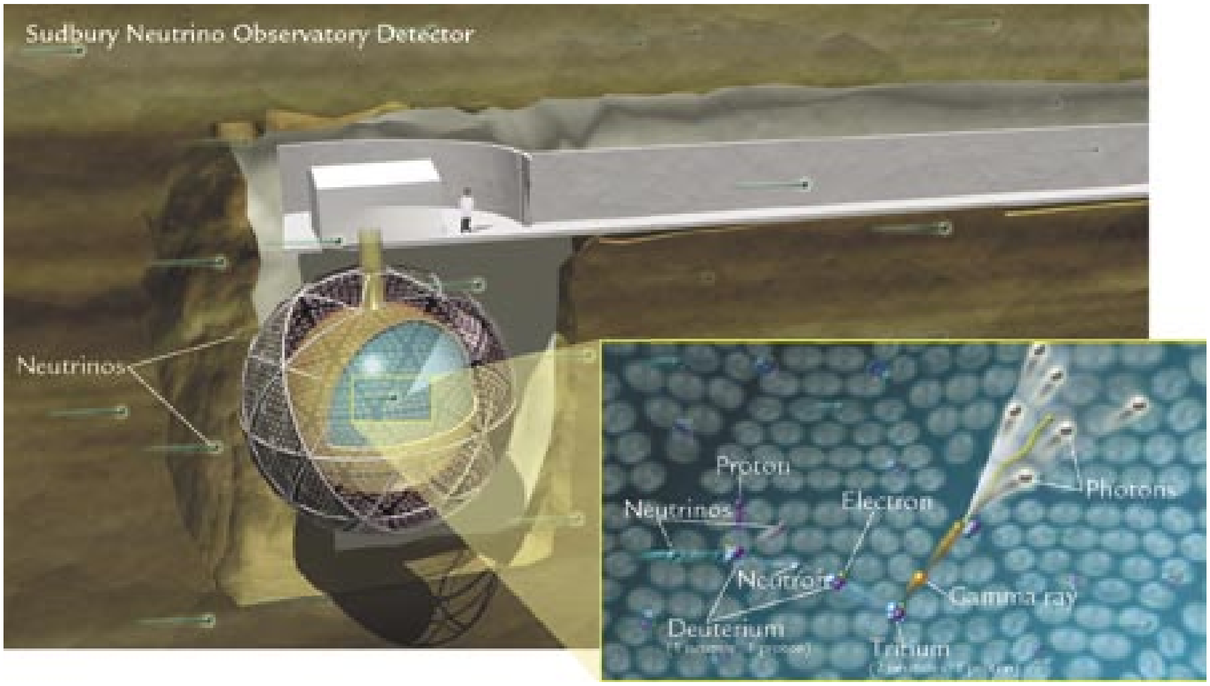


Figure 2. Three-dimensional rendering of SNO. In one of three neutrino reactions (in the inset) detected by SNO, a neutrino entering the detector interacts with a deuterium nucleus. The reaction produces a proton, neutrino, and neutron. The neutron is captured by another deuterium nucleus, producing a tritium atom in the process. The tritium atom decays and in that process releases a gamma ray, which then collides with an electron. Cerenkov light is emitted and detected by photomultiplier tubes that line inside of the SNO vessel.

failure properties, and equation of state (EOS) of materials important to the weapons program. Another EOS constraint can be obtained from volume temperatures. Neutron resonance spectroscopy (NRS) is used to determine volume temperatures by using Doppler-broadened neutron resonances to measure internal temperatures in dynamically loaded samples. Although still a nascent technique, our researchers plan on using NRS to measure the temperatures attained in shocked metals, at frictional interfaces, and in the "dead zones" of detonated chemical explosives.

P-23 also supports pRad and other experimental efforts and facilities such as DARHT (Dual-Axis Radiographic Hydrodynamic Test) facility by developing and fielding imaging systems and advanced detector systems. Historically, P-23 has been the locus for advanced imaging technologies developed to meet the demands of the weapons program.

Our imaging expertise is currently being applied to inertial-confinement-fusion (ICF) experiments via neutron pinhole imaging and to pRad. This simple yet powerful technique allows us to capture neutron images of capsules used in ICF experiments and thus contributes to improvements in capsule design. However, the application to ICF requires pinhole dimensions that push the limits for fabrication and fielding. In 2003, new milestones in pinhole fabrication were met, resulting in the highest-resolution images recorded to date, as well as the first "double-aperture" image. We continue to investigate different fast-imaging technologies especially hybrid/CMOS (complementary metal oxide semiconductor) that will provide needed infrared cameras and pixilated detector technology for pRad, hydrodynamic experiments, and SCEs. For example, P-23 has a new 3 MHz camera development work with Rockwell Scientific and University of California.

We also continue to preserve, analyze, and document the Nevada Test Site (NTS) and Pacific Proving Grounds weapons-test data to gain an understanding of physics and performance parameters of nuclear-weapons systems. P-23 analyzes imaging data from the pinhole neutron experiments (PINEX) and neutron-emission measurements from neutron experiments (NUEX) and threshold experiments (THREX) as well as continuous reflectometry for radius versus time experiments CORRTEX. The physicists and engineers who performed the original measurements are correlating and reanalyzing the data from different events, using new methodologies and improved computer and analytical techniques. Our aim is to develop better physics models and provide certified NTS data that will allow validation of the Advanced Simulation and Computing (ASC) program—an important goal of the stockpile stewardship program.

Nuclear Physics and Particle Astrophysics

The neutrino research effort in P-23 has focused on our continuing role in the Sudbury Neutrino Observatory (SNO) in Ontario, Canada (Figure 2). SNO is a 1000 metric ton, heavy-water Cerenkov detector operating deep underground in the Creighton mine in Sudbury, Ontario, Canada and can measure and separate all active flavors of neutrinos via charged-current, neutral-current, and elastic-scattering interactions on D_2O. Previous results employing a pure-D_2O detector provided direct evidence for resonant-enhanced solar-neutrino transformation and resolved the long-standing solar-neutrino problem. More recently, these results have been verified with unprecedented precision in the second phase of the SNO experiment. To accomplish this, NaCl was dissolved into the D_2O to enhance sensitivity to the neutral-current signal and separation from charged-current events. The SNO project has now entered its third and final phase wherein a discrete array of ultra-low-background helium-3 detectors have been deployed to separate all event classes on an event-by-event basis. This phase of the experiment promises to optimize the ultimate precision of the SNO experiment and offers a means to verify the solar-neutrino oscillations in a manner radically different than the previous two phases.

New efforts in P-23 are underway to elucidate further some of the most profound questions in modern physics following the seminal discoveries of neutrino mass and oscillations during the past few years. The Majorana project will attack the issue of absolute neutrino mass scale and character by exploiting a massive array of ultrapure germanium-76 in a search for the rare process of neutrinoless double decay. The Cryogenic Low-Energy Astrophysics with Neon project attempts to realize a liquid-neon-based target for low-energy solar neutrinos and cosmological dark matter.

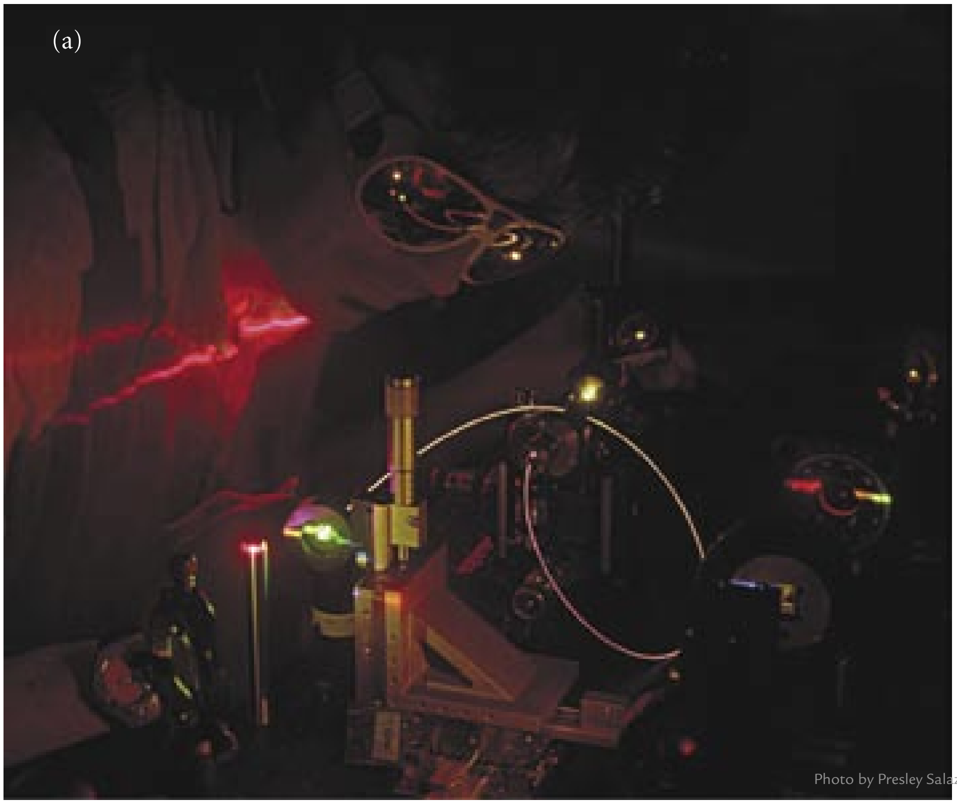
A broad and ambitious set of neutron-research projects involves colleagues in P-25 and a host of collaborating universities and institutions. Two notable examples are $n + p \rightarrow d + \gamma$ (NPDGamma) and ultracold neutron (UCN) experiments. The NPDGamma experiment will help researchers better understand the nature of weak interactions between strongly interacting hadrons by measuring the parity-violating directional gamma-ray asymmetry to an accuracy of 5×10^{-9}, i.e., to within approximately 10% of its predicted value. This project has involved the design, construction, and commissioning of a pulsed, cold-neutron beam line along flight path 12 (FP12) at the Lujan Neutron Scattering Center at the Los Alamos Neutron Science Center (LANSCE). The NPDGamma collaboration successfully commissioned the beam line at FP12 during 2004.

FP12 will also be used, upon completion of the NPDGamma experiment, to measure the electric dipole moment (EDM) of the neutron. The goal of the EDM project is to achieve over two orders of magnitude improvement to the limit of the EDM by using UCNs (produced and stored in a bath of superfluid helium-4) and superconducting quantum interference devices to monitor helium-3 precession. FP12 may also be used to measure pulsed cold neutron beta decay as a test of the standard model of electroweak interactions. This experiment incorporates an existing helium-3 spin-filter neutron polarizer and a new large-area spectrometer that are expected to reduce systematic errors to less than 0.1%. These fundamental and weapons-physics projects have driven improvements in detector capabilities, a hallmark of P-23.

P-23 is conducting an equally ambitious program of astrophysics research through its Milagro Observatory (Figure 3) located in the Jemez Mountains above Los Alamos, New Mexico, and by its participation in the High Resolution Fly's Eye (HiRes) experiment located in Utah. Milagro is the first detector of its kind—a large, water Cerenkov extensive-air-shower (EAS) detector—that can monitor the entire overhead sky in the TeV energy regime. Since its inception, Milagro has successfully detected the Crab Nebula with flux measurements that agree with values obtained using air Cerenkov telescopes. Building on this work, Milagro subsequently was used to produce a TeV gamma-ray map for the entire northern hemisphere.

The HiRes experiment looks for cosmic rays of energy greater than 10^{20} eV. HiRes detects the EASs that result from an

Figure 3. Milagro Observatory in the Jemez Mountains above Los Alamos.



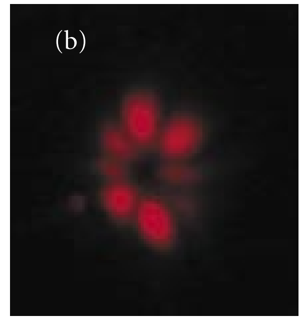


Figure 4. (a) Supercontinuum generation from a photonic crystal fiber obtained by propagation of 800 nm 100 fs pulses in it. (b) Far-field image of the output radiation obtained by converting Raman-shifted 1550 nm light in a photonic crystal fiber.

ultra-high-energy cosmic ray entering the atmosphere using two independent sites (12.6 km apart) to stereoscopically view the fluorescence caused by an event. A third experiment is the Wide-Angle Cerenkov Telescope (WACT) that employs an array of six atmospheric Cerenkov telescopes. WACT measures the lateral distribution of Cerenkov light created by EASs, allowing inference of the nuclear species of the primary cosmic ray. We have also re-examined archival data collected by the Burst and Transient Source Experiment and Energetic Gamma Ray Experiment Telescope satellites to discover a new high-energy component in one of the 24 gamma-ray burst emissions.

Finally, we have recently developed two experimental plans to search for a time variation of the fine-structure constant, alpha. The first plan involves comparison of three atomic optical frequency standards based on ion traps. The second plan involves a dysprosium-atomic-beam apparatus that will enable radio-frequency spectroscopy rather than optical-frequency metrology. P-23 also hosts an effort in nonlinear optics (Figure 4) which is focused on the next generation of fiber-based sources and detectors. The work performed on photonic crystals and photonic crystal fibers focuses on their application to frequency metrology, arbitrary signal generation, and spectrally broad ultrafast laser sources. The combination of nonlinear optics and structured waveguides is also being investigated with an eye towards extremely sensitive biodetection schemes for homeland defense applications. Finally, ultrafast pulses and optical nonlinearity are being used to develop the next generation of advanced and highly secure communication protocols.

Our mission is to solve challenging experimental-physics problems relevant to our national security—aiming to reduce the threat of war by helping to ensure the reliability of our nuclear-weapons stockpile and by limiting the proliferation of weapons of mass destruction, and maintain first-rate fundamental physics research. We anticipate many exciting developments in the coming years, including experiments to measure the time variation of the fine-structure constant, new studies into the nonlinear interaction of ultrashort laser pulses with structured fibers, a series of new SCEs at NTS to be conducted in collaboration with the United Kingdom, and a proposed experiment (Majorana) to measure the fundamental character of the neutrino via double beta decay.

P-24: Plasma Physics Group

Cris Barnes, Group Leader
Carter Munson and Mike Ray, Deputy Group Leaders

The Plasma Physics Group (P-24) at LANL has the mission "to nurture and use LANL's core discipline of experimental plasma science in basic and applied research to benefit LANL and the nation." The group applies an extensive knowledge of plasma physics, atomic physics, laser-matter-interaction physics, dynamic material properties, laser and pulsed-power technology, and plasma-diagnostic engineering and technology—all to study matter in the plasma state. P-24 addresses problems of national significance in inertial and magnetic fusion, laboratory plasma astrophysics, nuclear-weapons stewardship, conventional defense, environmental management, and plasma-based advanced manufacturing (http://www-p24.lanl.gov).

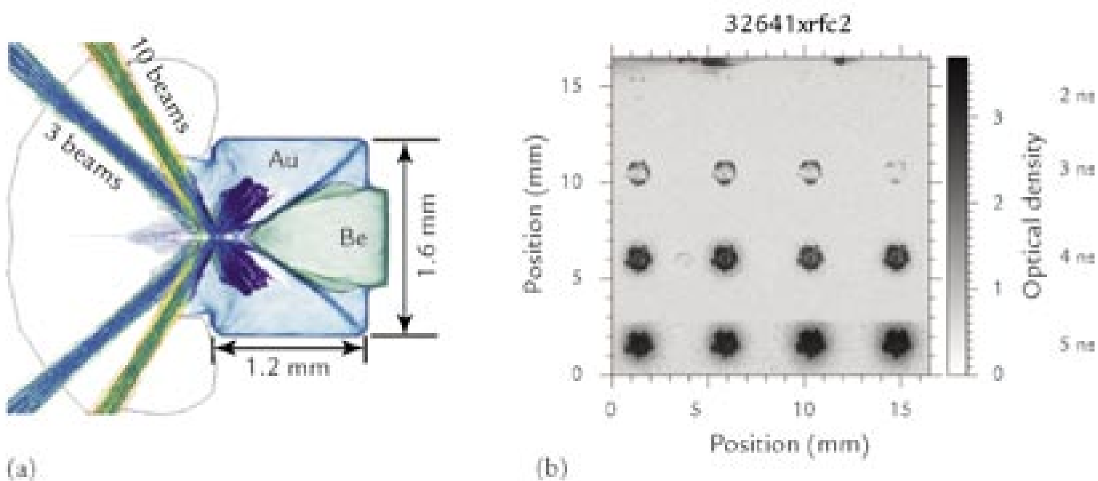


Figure 1. (a) Design of a gold vacuum hohlraum to be used at the Omega laser for beryllium microstructure stability studies. The laser beams enter from the left, and the 800 μm diam beryllium package is centered on the back wall to the right. (b) Gated x-ray framing camera images show the actual azimuthal filling of the hohlraum in time.

High-Energy Physics

The High-Energy-Density Physics and Fusion Team conducts target-physics experimental campaigns at our own Trident laser, as well as at the Omega laser at the Laboratory for Laser Energetics (University of Rochester) (Figure 1) and the Z pulsed-power facility at Sandia National Laboratories. Team members study physics issues relevant to achieving inertial fusion and relevant to weapons physics and basic high-energy-density physics, in particular, in the areas of laser-plasma instabilities, beryllium materials characterization, and the other properties of dynamic materials, fusion-burn diagnosis and capsule implosions, hydrodynamics and mix, and radiation flow and radiation hydrodynamics. The team is developing a variety of diagnostics for the National Ignition Facility (NIF) and this past year performed the first hydrodynamic and hohlraum shots on NIF.

The Trident Team performs experiments relevant to inertial-confinement fusion (ICF), weapons physics, and basic high-energy-density physics while operating the Trident laser facility (a three-beam, 500 J green laser with two separate target chambers and areas). Recent improvements to Trident have included a several-hundred-Joule few-microsecond capability for driving large flyer plates, and the facility now has a 20 J subpicosecond capability that is being enhanced to exceed 100 J and 200 TW (Figure 2). The team also works on advances in laser and optical science (Figure 3).

PLASMA PHYSICS

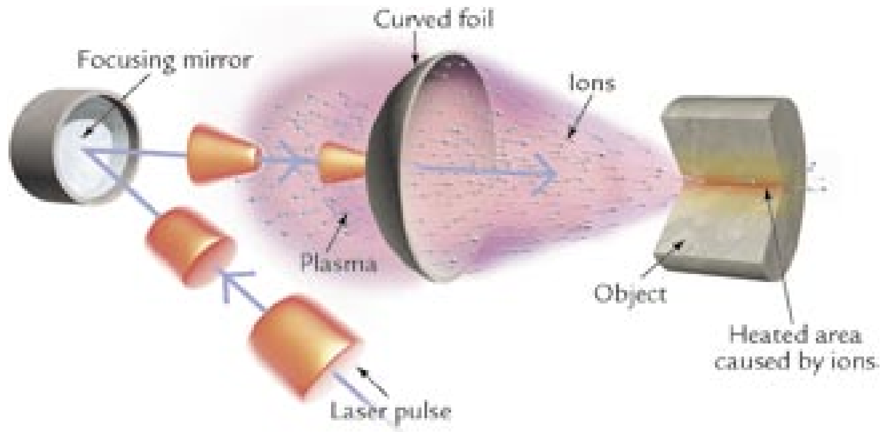


Figure 2. Ballistic focusing of a laser-accelerated ion beam into a secondary target. The secondary target will be heated isochorically to high temperatures while remaining at high density, recreating conditions found in the core of Jovian-like planets.

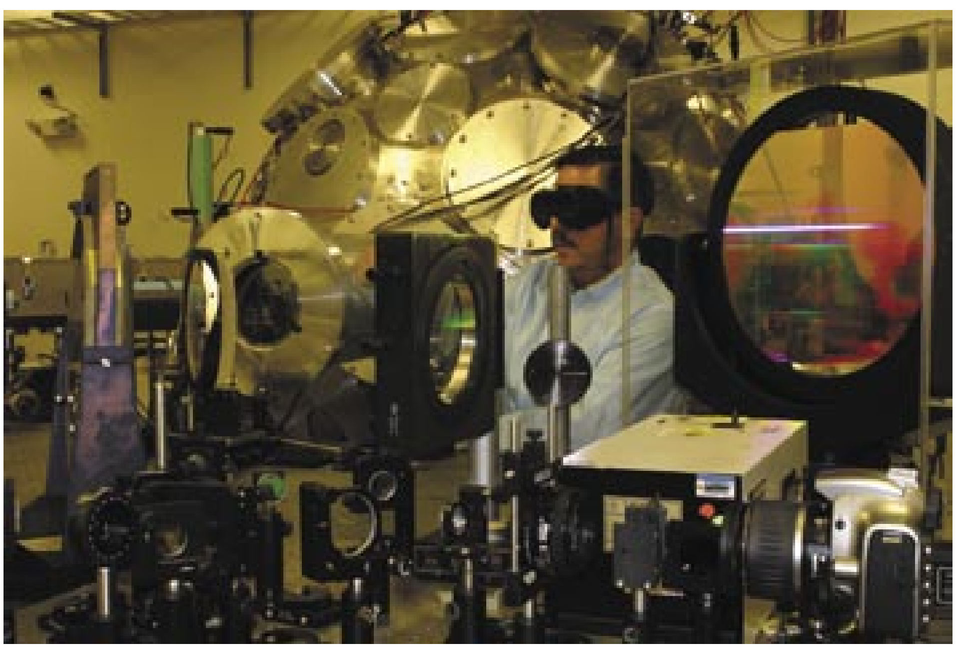


Figure 3. Tom Ortiz of P-24 adjusts the short-pulse compression optics (note the large gold grating to the right) on the north target chamber of Trident.

Plasma Physics

The Magnetic Fusion Team conducts experiments emphasizing innovative confinement concepts and diagnostics development. The primary focus is a field-reversed-configuration experiment aimed at investigating magnetized target fusion. Other projects include collaborations with scientists from the Massachusetts Institute of Technology, Princeton University, and the University of Washington. There is a growing focus on plasma science and laboratory plasma astrophysics, including a reconnection-scaling experiment and a new flowing-magnetized-plasma (FMP) experiment (Figure 4).

The Applied Plasma Technologies Team applies energetic nonequilibrium plasmas to environmentally conscious and industrially efficient processes with emphasis on basic physics, commercial applications, weapons-stockpile surety, and homeland defense. The work includes studies on nonthermal atmospheric-pressure plasmas and new applications such as plasma combustion and plasma aerodynamics (Figure 5).

Engineering and Administration

The Diagnostic, Engineering, and Operations Team provides engineering and technical support for many of the projects in the group. In addition to supporting experiments and diagnostics used at OMEGA, Trident, and soon NIF, the team designs, engineers, builds, and maintains diagnostic systems such as x-ray framing cameras (Figure 6), neutron imagers, gas Cerenkov burn-history diagnostics, streaked optical pyrometers, and target positioners. The team also operates a world-class research machine shop and provides photographic laboratory and digitization support.

The Administrative Team provides secretarial, operational, safety and security, computational and network, and general management support for the group.

P-24 Activities and Facilities

In the 2004 fiscal year, the group employed 92.3 full-time equivalent people on a nearly $20 million budget. The group typically has over 100 people working during the summer months, including a student population of 26 during summer 2004. To attract and educate these students, challenge and inspire our staff, and provide connections to visiting scientists, we created a more formal Plasma Physics Summer School (http://wsx.lanl.gov/RSX/summer-school/Summer_school_homepage.htm) with 21 lectures and seminars. The group maintains a vital post-doctoral researcher program with ten postdocs at present, including a Reines Fellow and a Director's Funded postdoc; two postdocs were converted to staff in 2004. The postdoc program has contributed to a demographic staff profile that is nearly flat with age. Over twenty percent of the postdocs and staff are foreign nationals as the group maintains a commitment to hiring the best scientific talent to meet its mission. The group recognizes that its future scientific work will involve ever more complicated measurements on complicated experiments. We thus have a significant and growing engineering staff in the group and are actively recruiting and hiring a larger proportion of technicians for the group, mostly at the entry level to be trained over the next decade by our outstanding corps of senior technicians.

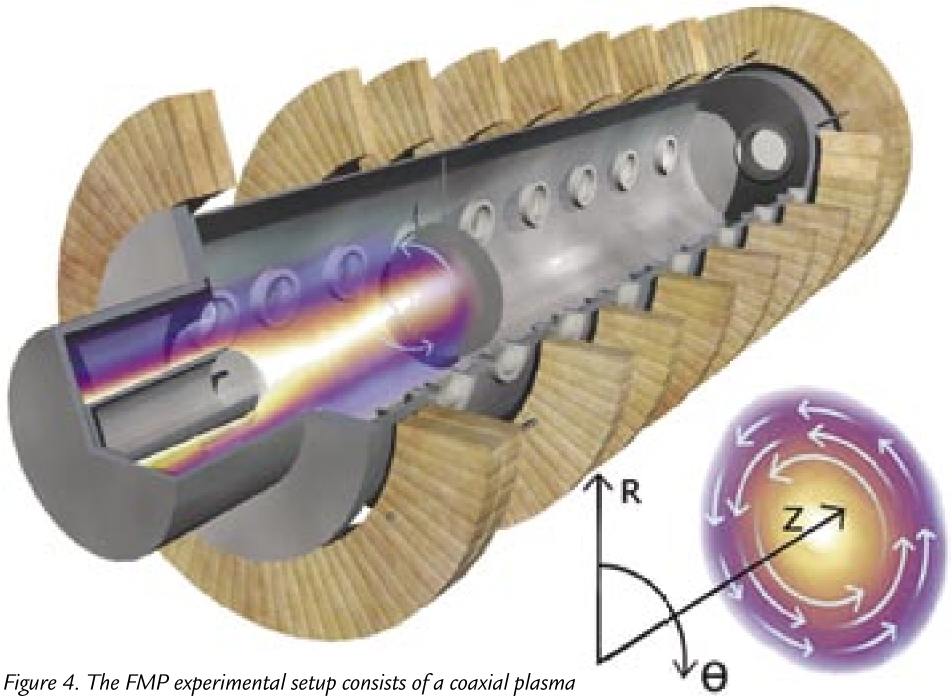


Figure 4. The FMP experimental setup consists of a coaxial plasma gun (front, left) mounted on one end of a large, cylindrical metal vacuum chamber surrounded by magnetic coils. The circular plate inside the chamber can be biased to different voltages, providing axial plasma confinement and some control over the potential profiles inside the plasma, which affects the azimuthal plasma rotation profile.

P-24 is located at Technical Area 35 in primarily six buildings covering a little over 53,000 sq ft. This area includes experimental laboratories for the Trident laser, the FRX-L magnetized-target-fusion experiment, the FMP experiment, the reconnection studies experiment, the Applied Plasma Technologies Laboratory, several laboratories for diagnostic development and checkout (i.e., x-ray sources, materials diagnostics, two laser laboratories, and an optical-diagnostic checkout facility), the machine shop and photo laboratories, and smaller laboratories associated with many of the technicians. Because P-24 is located near the Materials Science Division Target Fabrication Facility and major collaborators for our high-energy-density physics and fusion work, the group is well situated for its laboratory infrastructure.

P-24 Strategic Objectives

P-24 has strategic objectives in high-energy-density physics with specific plans to grow LANL's involvement in NIF and in the science campaigns aimed at studying primaries (Campaign 1, or "Boost") and secondaries (Campaign 4). Strategic objectives also include high-intensity short-pulse (subpicosecond) laser-matter interactions, the properties of materials under dynamic conditions, innovative fusion-confinement concepts such as magnetized target fusion, development of laboratory plasma astrophysics, and new applications of nonthermal plasmas. All of these are exciting fields of physics with strong growth potential that can contribute to achieving our vision "to be recognized as a world-leading organization for plasma physics and fusion science and technology, a home of trusted expertise, a place of choice for people to work and visit, and a partner of choice for sponsors and collaborators."

Figure 5. Effect of increasing the plasma power on plasma-assisted combustion. More power causes an increase in flame propagation speed, indicated by the movement of the flame from the top of the quartz tube (1) towards the electrodes [bottom, at location (2)].

P-24 Group Description

How we do business

- Emphasize personal growth and professional excellence—Cris Barnes, 505-665-5687, cbarnes@lanl.gov
- Implement improved operational efficiency and personal accountability—Carter Munson, 505-667-7509, cmunson@lanl.gov
- Continue to follow an academic alliance strategy—Cris Barnes
- Enhance our efforts to be recognized for technical excellence—Mike Ray, 505-665-6495, mray@lanl.gov
- Modernize the P-24 scientific and facility infrastructure—Cris Barnes

Main strategic accounts

- Maintain high-energy-density physics as a strategic account—Cris Barnes
- Grow our participation on NIF, leading LANL efforts on its scientific use and developing future diagnostics—Steve Batha, 505-665-5898, sbatha@lanl.gov
- Define a viable role for Los Alamos experimental work in ICF ignition, in particular, in implosion physics—George Kyrala, 505-667-7649, kyrala@lanl.gov
- Develop a robust program in Boost Physics—Carter Munson
- Achieve demonstration of magnetized target fusion—Tom Intrator, 505-665-2927, intrator@lanl.gov

Program development

- Become scientific leader in non-thermal plasma applications like plasma combustion—Lou Rosocha, 505-667-6493, rosocha@lanl.gov
- Define a strategy and grow our work in dynamic material properties—Damian Swift, 505-667-1279, dswift@lanl.gov
- Choose scientific thrusts in applications of short-pulse laser science and attract sponsors—Juan Fernández, 505-667-6575, juanc@lanl.gov
- Create a Lab-wide initiative in high-density magneto-inertial fusion in support of Office of Science strategic objectives—Glen Wurden, 505-667-5633, wurden@lanl.gov
- Create a supported focus research area in laboratory plasma physics in support of science-based prediction—Scott Hsu, 505-667-3386, scotthsu@lanl.gov
- Become funded as part of the U.S. International Thermonuclear Experimental Reactor program—Glen Wurden

Figure 6. Tom Archuleta of P-24 carefully installs the components of the Gated X-ray Detector for NIF. The fully computer-controlled systems operate inside a cooled air box.

Excerpted from LA-14202-PR

P-25: Subatomic Physics Group

Martin Cooper, Group Leader
Jon Kapustinsky and Wesley Wilburn, Deputy Group Leaders

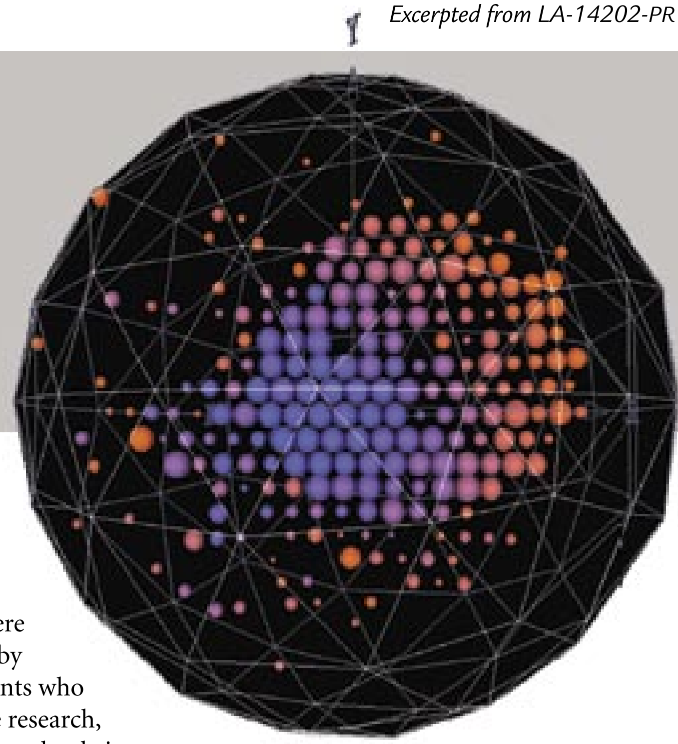


Figure 1. The colors in this typical MiniBooNE neutrino event relate to elapsed time—the blue represents early PMT hits and the orange represents later photomultiplier-tube hits. In this particular data event, there were fewer than six veto hits and over 200 tank hits.

The Subatomic Physics Group (P-25) was created in 1994 as part of a reorganization of Physics (P) Division initiated by former P Division Leader Peter Barnes. The scientific staff of P-25 was formed from P-2 (Medium-Energy Physics) and the research groups MP-4 and MP-10 of the Medium-Energy Physics (MP) Division. The common thread uniting these groups was leadership in investigations of issues of subatomic physics that could be addressed in experiments at a number of accelerator facilities, including the Los Alamos Meson Physics Facility (LAMPF), currently known as the Los Alamos Neutron Science Center (LANSCE); the Fermi National Accelerator Laboratory (FNAL); the European Organization for Nuclear Research (CERN); and the Superconducting Super Collider. Because of the diverse physics being conducted in MP-4, MP-10, and P-2 and tight funding at the time, it was clear that the group would have to undergo a consolidation of its research priorities. John McClelland (now Deputy Director for Experimental Physics in the Weapons Physics Directorate at LANL) was the first group leader of P-25, and under his direction the research priorities were narrowed, and about half of the group redefined its area of focus.

New themes in P-25 became studies of fundamental issues of the standard model (the primary focus) and the search for a basis for stronger collaborations between fundamental physics and the weapons community. In carrying out its experimental investigations, P-25 staff members often participate in large-scale collaborations that involve physicists from universities and institutions from around the world, and the group contributes to or leads experiments at a variety of facilities. The intellectual atmosphere in the group is enhanced by local workshops, by students who come to participate in the research, and by a small theory group that brings in numerous theory visitors involved in research areas of interest to the group. A few of the current programs and projects in P-25 are featured in the activities described below.

The group's current experimental activities evolved largely from the research priorities established during the consolidation of the mid 1990s. Neutrino physics, with an emphasis on searches for neutrino oscillations, now focuses on the MiniBooNE experiment at FNAL (Figure 1).

This experiment is the first phase of the larger Booster Neutrino Experiment (BooNE) that will definitively test results from the Liquid Scintillator Neutrino Detector (which took data from 1993–1998 at LAMPF) to confirm neutrino oscillations and will precisely measure the oscillation parameters. This experiment will also test *CP* (charge conjugation/parity transformation) and *CPT* (the combined operation of charge conjugation, parity inversion, and time reversal) violation in the lepton sector.

The Neutrino Physics Team also has interest in exploring new methods of detecting "double beta decay" of nuclei to further understand the nature of the neutrino. In addition to neutrino studies, P-25 is involved in the relativistic-heavy-ion investigations currently under way at the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory. The goal of these investigations is to create and study the exotic properties of a primordial quark-gluon plasma in a laboratory. This activity was an outgrowth of the successful relativistic-heavy-ion program at CERN, which was under way in P Division at the time P-25 was formed, and the joint research program in P and MP Divisions

RESEARCH HIGHLIGHT
PHYSICS DIVISION

to study Drell-Yan and charmonium physics at FNAL.

Members of P-25 are involved in the development of a silicon vertex detector upgrade for the PHENIX (Pioneering High-Energy Nuclear Interaction Experiment) detector at RHIC that enhances the capability for studying the gluon distributions in colliding nuclei and the early evolution of the formation of the quark-gluon plasma by directly detecting heavy-quark decays.

Detecting pairs of muons produced in deuteron-gold and gold-gold collisions at RHIC, members of P-25 are obtaining mass spectra of the J/ψ (a particle consisting of a charmed and an anticharm quark). Such spectra have been long awaited as a diagnostic of the quark-gluon plasma.

The High Resolution Fly's Eye (HiRes) experiment at the Dugway Proving Grounds in Utah is measuring ultra-high-energy cosmic rays (UHECRs) ($> 10^{18}$ eV) with detectors sensitive to the air fluorescence of showers caused by cosmic rays entering the atmosphere—HiRes is now helping researchers quantify mechanisms of production and propagation of UHECRs.

Another theme in P-25 involves neutron physics at LANSCE, which aims to study symmetry violation and search for physics beyond the standard model. Members of P-25 are currently planning a novel search for the electric dipole moment (EDM) of the neutron, an interest that grew out of their earlier work in fundamental symmetries.

In designing the experiment aimed at improving the limit on the EDM of the neutron, the team made the first measurement of the dielectric strength of helium-4 over a distance range of 1 to 7 cm with an area of 400 cm^2. The fact that voltages around 100 KeV/cm can be held is an important step forward in the feasibility of the experiment. The team also made its first sample of ultrapure helium-4 with the hope that it will have a purity of less than 10^{-12} atoms of helium-3. The team also measured the cohesive force of Metglas at a temperature of 1.2 K and found it to have adequate magnetic shielding properties for the experiment.

Figure 2. Members of P-25 performing calibration tasks before a pRad shot.

P-25 is collaborating with P-23 to provide better sources of ultracold neutrons (UCNs)—neutrons that can be trapped by ordinary materials and then used for a variety of experiments that probe fundamental quantities with high precision. The team has recently commissioned tests of a full-scale UCN source based on their earlier pioneering development of the world's most intense source of UCN using solid deuterium.

Proton radiography (pRad)—a technology that images dynamic variations of macroscopic objects over small time intervals with millimeter spatial resolution—is a new activity that was inspired by P-25's familiarity with accelerator physics and its understanding of advanced detectors for imaging and handling high data rates (Figure 2).

Application of the same underlying principles is also contributing new ideas for homeland defense. P-25's pRad program has three goals: (1) to demonstrate that radiography with high-energy protons is a suitable technology for meeting the goals established for advanced radiographic imaging, (2) to advance the technology of charged-particle radiography, and (3) to apply radiography with 800 MeV protons to the needs of the stockpile stewardship program. Members of the pRad Team recently commissioned a new radiography system that images dynamic events with an order of magnitude higher spatial resolution and another system that significantly improves sensitivity to thin objects. A prototype electron-radiography system, designed by P-25 and constructed at the Idaho Accelerator Center, was used to continue investigations in the use of electrons as direct probes for static and dynamic radiography of thin systems.

Recent theoretical activity in P-25 has focused on parity violation in chaotic nuclei, deep inelastic scattering, and Drell-Yan reactions as a means to explore quark propagation in nuclei, quantum chromodynamics at finite temperatures, and phase transitions in the early universe.

P-25 is making numerous contributions to homeland defense based on novel applications of nuclear-physics techniques. This includes muon radiography, which is a high-sensitivity detection technique relying on natural radiation that could aid in the surveillance for contraband special nuclear material, and Very Large Area Neutron Detector, which applies neutrino-detector technology to the identification of special nuclear materials.

P-25 group members continue to be active in education and outreach activities, both as participants in programs sponsored by LANL, whereby high school, undergraduate, and graduate students work on projects within the group, and as individual citizens who volunteer their time for various activities (visit http://users.hubwest.com/hubert/mrscience/science1.html for information about this activity).

The cutting-edge science described here not only advances fundamental knowledge and spawns creative ideas for new technology but also is a key ingredient of LANL's ability to attract and retain the high-caliber talent it needs to fulfill its national security mission.